

Physiological Consequences of Boot Material and Sole Type in Men and Women Firefighters

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Abstract

Fourteen men and 13 women firefighters walked on a treadmill and climbed a stair ergometer while wearing stitched-soled and cement-soled leather boots. During treadmill exercise, significant ($p \leq 0.05$) decreases in VO_2 (-4.5%), and VO_2/kg (-4.6%), were observed in men for cement as compared to stitched soles. Significant decreases in VO_2 (-4.8%), and VO_2/kg (-4.0%) were observed in women. These decreases were seen despite the lack of difference in boot weight, a factor that has been shown to increase metabolic and respiratory variables.^(1,2) A significant ($p \leq 0.05$) gender effect was observed for VO_2/kg and HR. During stair ergometry, insignificant decreases of 1 – 3% were observed for VE, VO_2 , VCO_2 , VO_2/kg , and HR in men and women for cement as compared to stitched soles. A significant ($p \leq 0.05$) gender effect was observed for VO_2 , VO_2/kg , and HR.

Introduction

The intensity of energy expended by firefighters performing fire fighting tasks is generally agreed to be in the heavy to very heavy range. According to the National Fire Protection Association, an estimated 80,100 firefighter injuries occurred in the line of duty in 2007.⁽³⁾ The top two leading causes of injury were overexertion (24.4%) and falls (27.3%). Of all 102 firefighter fatalities in 2007, 40 were the result of exertion/stress. There are two general types of certified structural fire fighting boots in use today: 13"-16" rubber bunker boots and 8"-16" leather boots. Leather boots are produced with either a stitched or cement sole. A 5 – 12% increase in oxygen consumption per kg of weight added to the foot has been observed;^(1,2) however, the effect of sole type has not been investigated. The purpose of the current study was to determine the effects of sole type on men and women firefighters' metabolic variables during simulated firefighting tasks.

Methods

Fourteen career men and 13 women (12 career, 1 volunteer) firefighters between the ages of 18 and 40 were recruited and provided informed consent for this study. Men (mean age 31 yrs, wt 93 kg, ht 178 cm) were recruited from the Morgantown, WV area, while women (mean age 31, wt 73 kg, ht 168 cm) were recruited from West Virginia, western Maryland, northern Virginia, and eastern Ohio. All subjects, while wearing full turnout clothing, a 10.5-kg backpack, gloves, helmet, and one of four randomly assigned pairs of NFPA-certified firefighter boots, walked for 6 minutes at 3 mph on a treadmill while carrying a 9.5-kg hose (Fig. 1) and climbed a stair ergometer for 6 minutes at 45 steps per minute (6-inch step height, Fig. 2). Boot models and characteristics are shown in Table 1. The boots selected had similar weights; the largest mean difference in boot weight was 0.3 kg. Task order was randomized for each pair of boots. Minute ventilation (VE), oxygen consumption (VO_2 and VO_2/kg), CO_2 production (VCO_2), respiratory quotient (R), and heart rate (HR) were measured using a portable metabolic measurement system (COSMED, Italy), and an average of the breath-by-breath data from minute six was used for analysis. Comparisons of gender, sole type, and boot weight were made using analysis of covariance with repeated measures.

Table 1. Boot models and characteristics.

Model	Sole Type	Weight	Height	Heel Area
S1	Stitched	2.6 kg men	36.8 cm	81.3 cm ²
		2.4 kg women		
S2	Stitched	2.9 kg men	36.6 cm	83.2 cm ²
		2.5 kg women		
C1	Cement	2.8 kg men	36.8 cm	81.3 cm ²
		2.4 kg women		
C2	Cement	3.0 kg men	30.2 cm	82.6 cm ²
		2.6 kg women		

Results

During treadmill walking, significant gender differences ($p \leq 0.05$) were observed for VO_2/kg , and HR (Table 2). Significant effects of sole type ($p \leq 0.05$) were observed for VO_2 , and VO_2/kg in men and women. During stair ergometry, significant gender differences ($p \leq 0.05$) were observed for VO_2 , VO_2/kg , and HR (Table 3). There were no significant effects of sole type. Due to the similarity in weight of the models tested, there were no significant additional effects of boot weight on any variables during either mode of exercise.

Table 2. Mean (SD) treadmill results for men and women.

Boot	VE (L/min, BTPS)	VO_2 (L/min, STPD)	VO_2/kg^* (ml/kg/min, STPD)	VCO_2 (L/min, STPD)	R	HR* (bpm)
Men						
S1	48.0 (7.9)	1.95 (0.25)	21.6 (2.3)	1.62 (0.25)	0.84 (0.06)	142 (15)
S2	50.0 (8.0)	2.03 (0.26)	22.5 (3.0)	1.68 (0.25)	0.85 (0.06)	148 (20)
C1	48.8 (8.3)	1.91** (0.28)	21.1** (2.9)	1.66 (0.23)	0.85 (0.05)	143 (22)
C2	49.5 (10.7)	1.94** (0.35)	21.3** (2.5)	1.66 (0.27)	0.87 (0.06)	144 (14)
Women						
S1	52.2 (8.8)	1.83 (0.20)	25.8 (2.4)	1.63 (0.20)	0.85 (0.06)	159 (10)
S2	52.63 (8.1)	1.86 (0.21)	25.3 (3.1)	1.62 (0.22)	0.86 (0.06)	162 (11)
C1	47.6 (8.0)	1.76** (0.25)	24.1** (3.2)	1.54 (0.24)	0.87 (0.04)	158 (17)
C2	50.6 (10.4)	1.83** (0.28)	25.1** (4.2)	1.63 (0.29)	0.86 (0.04)	161 (21)

* Significant ($p \leq 0.05$) effect of gender

** Significant ($p \leq 0.05$) effect of sole type – cement compared to stitched

Table 3. Mean (SD) stair ergometer results for men and women

Boot	VE (L/min, BTPS)	VO_2^* (L/min, STPD)	VO_2/kg^* (ml/kg/min, STPD)	VCO_2 (L/min, STPD)	R	HR* (bpm)
Men						
S1	54.8 (9.3)	2.17 (0.27)	24.0 (2.8)	1.93 (0.30)	0.90 (0.07)	159 (16)
S2	55.8 (11.7)	2.19 (0.32)	24.1 (2.8)	1.94 (0.33)	0.90 (0.06)	162 (15)
C1	55.0 (9.0)	2.16 (0.28)	23.8 (2.6)	1.98 (0.27)	0.89 (0.06)	156 (18)
C2	55.0 (10.2)	2.20 (0.32)	24.3 (2.7)	2.02 (0.29)	0.92 (0.06)	159 (16)
Women						
S1	54.6 (13.6)	1.90 (0.16)	25.9 (1.6)	1.73 (0.20)	0.89 (0.08)	167 (12)
S2	51.84 (8.6)	1.88 (0.16)	25.8 (2.1)	1.71 (0.21)	0.90 (0.07)	164 (12)
C1	49.4 (10.9)	1.81 (0.23)	24.7 (2.5)	1.65 (0.29)	0.89 (0.05)	168 (11)
C2	52.5 (10.8)	1.86 (0.23)	25.4 (2.5)	1.71 (0.28)	0.91 (0.05)	169 (18)

* Significant ($p \leq 0.05$) effect of gender



Fig. 1 Treadmill walking



Fig. 2 Stair ergometry

Discussion

Table 4 shows the estimated percent decrease for cement-soled as compared to stitched-soled boots for metabolic and respiratory variables. A 4.3% decrease in VE, observed in men and women during treadmill walking, would result in an approximate 2 minute decrease in service time for a 45-min SCBA cylinder.

Table 4. Percent change for cement versus stitched soles ($p \leq 0.05$)

Task	VE (L/min, BTPS)	VO_2 (L/min, STPD)	VO_2/kg (ml/kg/min, STPD)	VCO_2 (L/min), STPD	HR (bpm)
Treadmill					
Combined	-4.3%	-4.7%*	-4.3%*	-2.0%	-1.6%
Men	-4.4%	-4.5%*	-4.6%*	-2.0%	-1.7%
Women	-4.2%	-4.8%*	-4.0%*	-1.9%	-1.6%
Stairs					
Combined	-2.9%	-2.1%	-1.9%	0.0%	-0.7%
Men	-2.8%	-1.9%	-2.0%	0.0%	-0.7%
Women	-3.0%	-2.2%	-1.8%	0.0%	-0.6%

* Significant ($p \leq 0.05$) effect of sole type

The mechanism for the observed significant decreases in VO_2 and VO_2/kg for cement-soled boots during treadmill walking is unknown. However, additional data not shown here and collected during slightly different walking tasks show significantly greater ankle range of motion with cement soles as compared to stitched soles. Boot weight equaled approximately 3.5% of body weight for men and 4% for women. During treadmill walking, total gear and hose weight equaled approximately 33% of men's body weight and 42% of women's body weight. Therefore, significant effects of sole type were observed during walking even though men and women were wearing heavy protective clothing and equipment.

Conclusions

- 1) Significant 4 to 5% decreases ($p \leq 0.05$) in VO_2 and VO_2/kg were observed for cement-sole boots compared to stitched-sole during treadmill walking with hose.
- 2) Percent changes seen during walking are almost identical for men and women; effects of sole type are not influenced by gender-dependent walking strategies.
- 3) Insignificant 2 to 3% decreases in metabolic and respiratory variables were observed during stair ergometry.
- 4) Gender effects were observed for VO_2 and HR for both treadmill walking and stair climbing.

References

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